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A PROTOTYPE COMMERCIAL FORCED-AIR PRECOOLER

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and

Departments of Fruit Crops and Agricultural Engineering
Agricultural Experiment Station
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PREFACE

This report presents information on the design and construction of an experimental continuous-flow, forced-air precooler. The precooler is a scaled-down prototype designed to test the feasibility of commercial use in fruit and vegetable packinghouses. The prototype was constructed by the Durand Machinery Co., Woodbury, Ga., under contract with the Department of Agriculture.

Development of the precooler grew out of research conducted cooperatively by the Florida Agricultural Experiment Station, University of Florida; the Georgia College of Agriculture Experiment Stations, University of Georgia; and the Transportation and Facilities Research Division, Agricultural Research Service, United States Department of Agriculture.

The work was performed under the general supervision of Joseph F. Herrick, Jr., investigations leader, Handling and Facilities Research Branch, TFRD, ARS, and A. L. Krezdorn, Head, Department of Fruit Crops, University of Florida, Gainesville.

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A PROTOTYPE COMMERCIAL FORCED-AIR PRECOOLER

by A. H. Bennett, J. Soule, and G. E. Yost ^{1/}

INTRODUCTION

Precooling fresh fruits and vegetables has proven to be a valuable aid to product quality maintenance during transportation and storage. Most fruit and vegetable products, particularly in the Southeast, are precooled at the packing-house by hydrocooling the product as it moves through the packing line (in-line cooling). Exceptions are the vacuum cooling of certain leafy vegetables, which is usually done at vacuum-cooling plants, and the air cooling of some products in heavily refrigerated storage rooms or in truck trailers or rail cars.

In-line cooling is generally accomplished by hydrocooling because water has a more efficient and effective heat-transfer capability than air. Water, however, has certain disadvantages that prohibit its use with some products and make it less desirable for others. Such undesirable features as contamination by waterborne fungi and bacteria, possible stresses imposed upon the product because of sudden exposure to cold water, and sanitation problems are eliminated when air is used as a cooling medium. A quick method of air precooling would be especially useful for products that, because of physical, physiological, or sanitary reasons, cannot be hydrocooled. Chief among such products are strawberries, blueberries, snap beans, and butter beans.

In conventional precooling systems, water cools much faster than air. The cost for rapid air precooling, in comparison to hydrocooling, is generally prohibitive. However, should the temperature, flow rate, and method of distribution of air be regulated in such a way that the cooling rate and cost of air systems approach the rate and cost of hydrocooling, air precooling may become a commercially acceptable practice.

Research to investigate this feasibility was carried out in test facilities at the packinghouse of the Fruit Crops Department of the University of Florida. Results from studies on citrus fruits were strongly indicative of commercial potential.

On the basis of this research and additional laboratory tests, an experimental continuous-flow forced-air precooler was designed, and from this

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design a scaled-down prototype of a commercial machine was constructed. The prototype was built on a 40-foot-long standard truck trailer to facilitate testing of cooling effectiveness with respect to cost on different fruits and vegetables at various locations. Preliminary research indicates that precooling by this technique can be accomplished at a reasonable cost for commercial use. Tests are presently being conducted with sweet corn, string beans, butter beans, peaches, and citrus fruit.

The present report describes the design and construction of the prototype precooler and the test instruments installed in the cooler to measure its performance. The precooler uses the principle of exposure of the surface of individual products to a cold air blast as the products move along a conveyor.

Application of this principle of air precooling is not new. In 1938, Pentzer and Barger successfully cooled grapes by exposing the fruit surface to high-velocity chilled air.^{2/} In 1947 and 1948, tunnel coolers were constructed to test the effectiveness of this air cooling method when applied as a continuous in-line system. This work resulted in the development of systems that were put into commercial use.

The precooler described in this report differs from earlier designs by employing the concept of chilling the air substantially below the freezing point of the product being cooled. This permits a reduction in air velocity that results in a significant reduction in fan power requirements. In this way, air can be used more efficiently as a cooling medium.

DESIGN OF THE PRECOOLER

In forced-air precooling, cooling rate depends upon the air temperature with respect to the product temperature, air velocity, the amount of product surface area exposed to the air, and product characteristics.

The optimum difference between air temperature and product temperature is 30° to 40° F. Considering that products normally enter a cooler at 80° to 90° and the desired product temperature is 40° to 50°, air temperature for most efficient cooling should range from 50° at the entrance of a cooler down to about 10° at the exit. Air below 32° has not generally been used to cool fresh fruits and vegetables for fear of freezing the product. Extensive research on citrus fruits has shown, however, that air substantially below 32° may be used without injury, if the cooling time is regulated so that the surface temperature of the product is not reduced to the freezing point. Results of the tests with citrus fruits also indicated that large amounts of air are not required for effective cooling. The optimum approach velocity was found to be between 250 and 300 feet per minute. This low airflow rate substantially reduces the fan power requirement for fast air cooling, hitherto considered as prohibitive.

To achieve an efficient cooling system design and also a desirable product environment, the precooler was designed so that the temperature of the air and

^{2/} Pentzer, W. T., and Barger, W. R. Precooling grapes in tunnel coolers. U.S. Bur. Plant Ind., Soils, and Agr. Engin. H.T.&S. Office Rpt. 198, 7 pp. 1948.

the product are progressively reduced from the entrance to the exit of the cooler. The temperature difference between the air and the product therefore remains about the same throughout the cooling process. This technique is called staging. It simulates counterflow heat transfer, theoretically the most efficient type of heat exchange.

The prototype precooler consists of a 5-stage cooling tunnel (fig. 1). Each stage is an independent cooling unit (fig. 2). In the cooling tunnel,

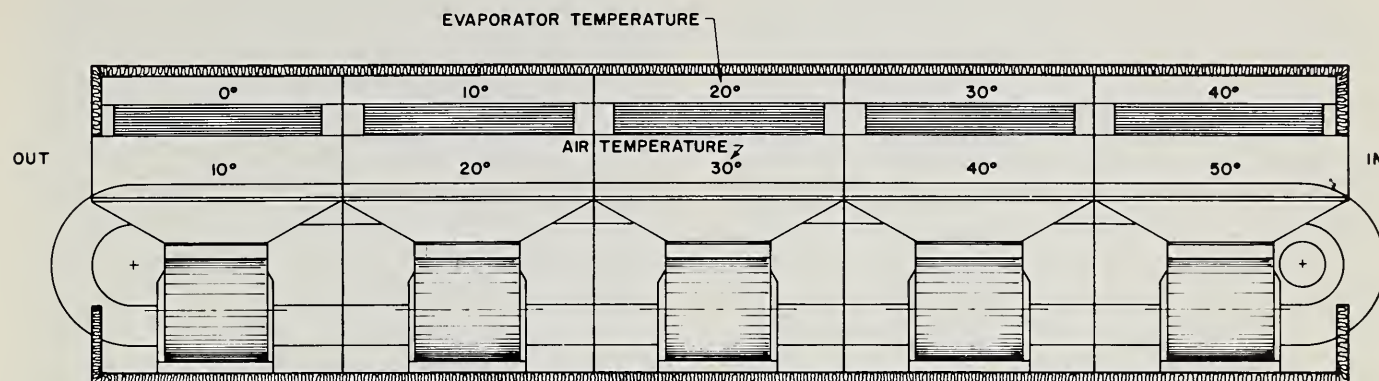


Figure 1.--Schematic side view of the prototype forced-air precooler.

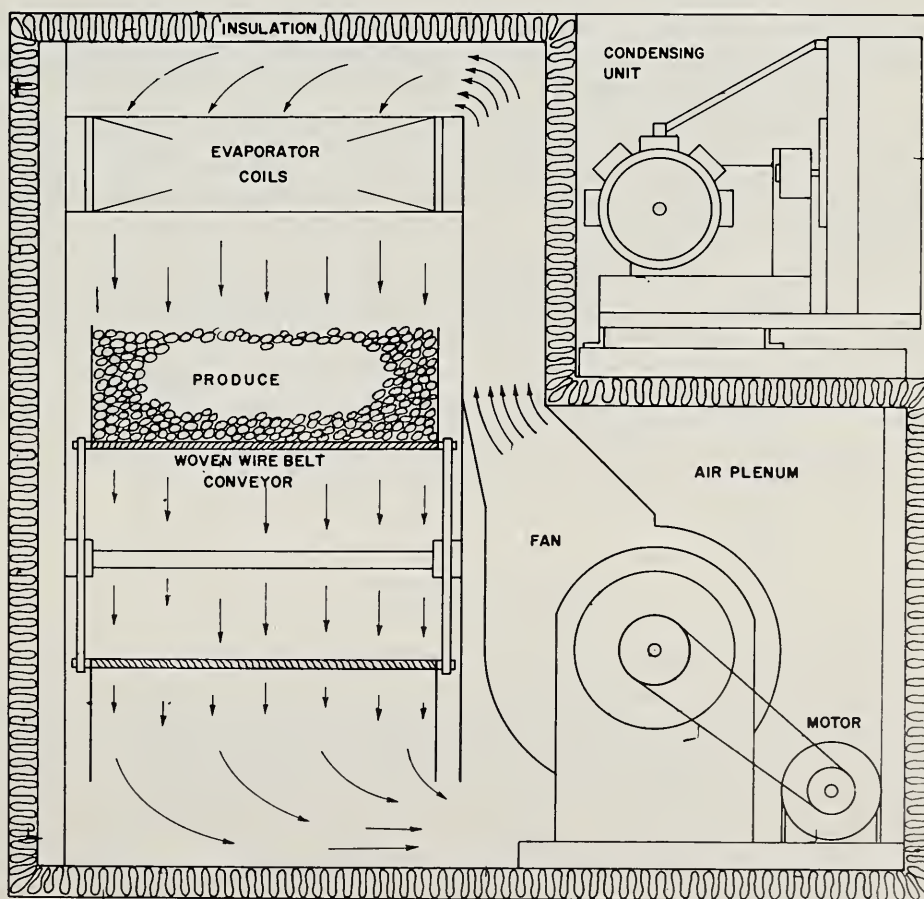


Figure 2.--Cross section of end view of one unit of the 5-stage precooler. Arrows indicate pattern of air travel.

products may be conveyed in bulk or in packages that permit free flow of air across the product surface. Maximum product surface area is exposed by forcing air uniformly through voids between the products. When containers are used, they should be fitted closely together to reduce the bypass of air around them. The precooler is designed to permit continuous flow of the product through the cooling tunnel, as in conventional flood- or bulk-type hydrocoolers, so that product flow through the cooler may be synchronized with the flow through the packinghouse.

SPECIFICATIONS

The complete prototype machine is 8 feet wide, 7 feet 9 inches high, and 30 feet long. It is mounted on a 40-foot-long, single axle, dual wheel, 12-ton trailer.

It has a capacity to cool up to 50 hundredweight per hour. Specific capacity will vary according to the size, shape, temperature, and other characteristics of the product being cooled.

Conveyor System

The conveyor system consists of two parts: (1) The main conveyor through the tunnel, and (2) an external conveyor to transfer products from a belt, or elevator, to the main conveyor. The main conveyor is 3 feet wide by 30 feet long. It is equipped with sideplates to accommodate loose products up to 1 foot in depth. It is constructed of 10-gage, 3/4-inch balanced weave wire mesh, with dual side-chain drive, supported by rollers and idler pulleys. The supporting rollers are placed on 1-foot centers. Drive mechanism consists of a variable-speed drive with a 4 to 1 ratio to provide a cooling tunnel retention time of 15 minutes to 1 hour.

The external conveyor is 3 feet wide by 3 feet long. It is designed for easy removal when not needed, as in the case of cooling certain packaged products. It can also be raised or lowered as needed. The external conveyor and entrance end of the cooling tunnel are shown in figure 3, and the discharge end of the main conveyor is shown in figure 4. Canvas curtains are installed at both ends of the cooling tunnel to reduce air leakage.

Cooling System

The basic cooling-system equipment is shown in figure 5.

The five cooling units operate independently of each other, and each produces a different air temperature. The five independent units are referred to as stages 1 through 5, from entrance to exit, respectively. The condensing units are shown in figure 6. Stage 1 unit is in the foreground. Stages 1, 2, and 3 are equipped with 5-horsepower compressors. Stages 4 and 5 use 7.5-horsepower compressors.



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Figure 3.--External conveyor and canvas curtain in place at entrance to cooling tunnel.



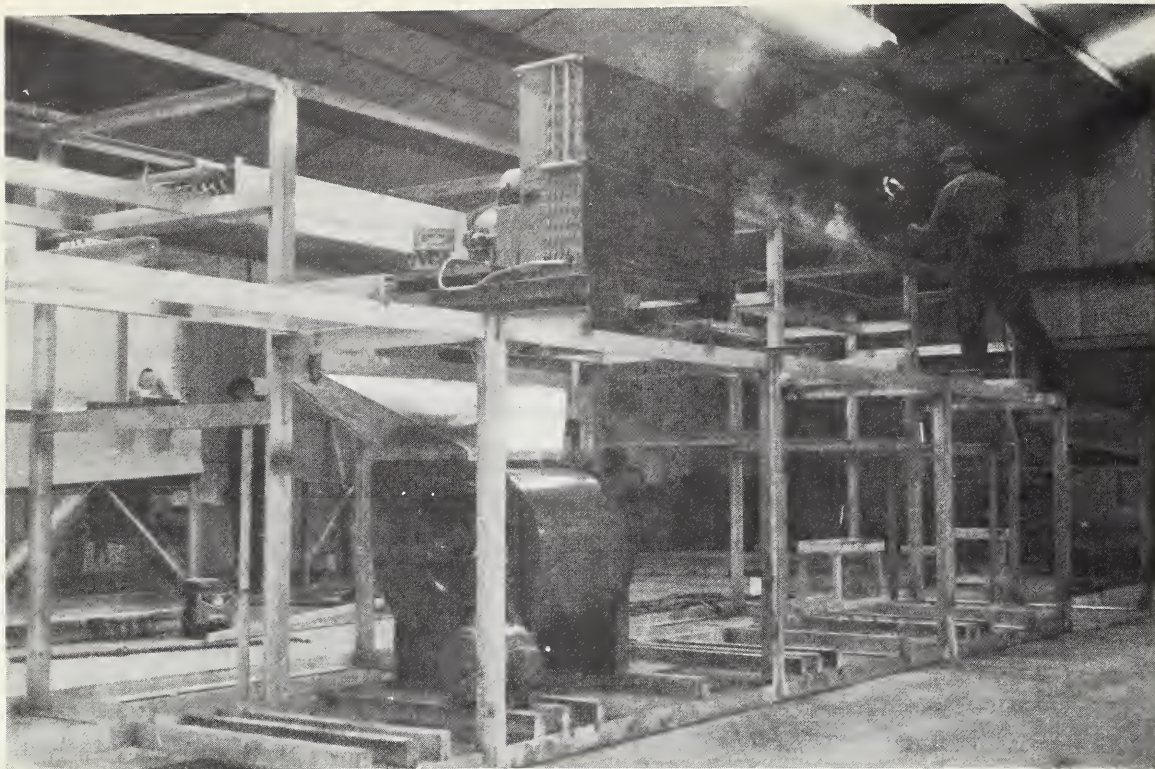
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Figure 4.--Discharge end of cooling tunnel, with curtain above main conveyor removed.

Design specifications required that each unit have a minimum capacity of 3 tons of refrigeration when operating at specified conditions. To accomplish the step-down effect in air temperature, the temperature in the cooling (evaporator) coils is normally as follows:

<u>Stage</u>	<u>Temperature ° F.</u>
1	40
2	30
3	20
4	10
5	0

To provide an equivalent amount of refrigeration in each unit, compressor size must be increased as cooling-coil temperature is reduced. Hence, compressor size is progressively increased from entrance to exit. In order to meet the minimum specification requirement, the contractor supplied condensing units that total approximately 19 tons of refrigeration capacity when operated as specified.



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Figure 5.--Cooling-system equipment for one unit mounted on frame during construction of forced-air precooler. Evaporator coil and condensing unit are shown in upper center with the fan and motor directly below.

The evaporator coils are each 24 inches wide and 60 inches long. They consist of five rows of 3/4-inch O.D. pipe having four fins per inch. Fin spacing was selected to allow some frosting without causing appreciable resistance to airflow through the coils.

Each unit is equipped with one standard duty, double-inlet, double-width, backward-curve blade fan having capacity to deliver approximately 5,000 cubic feet of air per minute when operating against a static pressure of 2 inches water gage. Fan wheel diameter is 16½ inches. The fan is equipped with variable-speed pulleys to permit adjustment in fan speed. Fan power requirement varies, depending upon the resistance the product offers to air movement, the amount of frosting on the coil, and the speed of fan rotation. Fan power requirements should never, under any conditions, exceed 3 horsepower, and could conceivably be as low as 1.5 horsepower without jeopardizing cooling. Each unit is equipped with a 3-horsepower motor to drive the fans.

Construction Materials

Removable metal sidewall and top panels of the cooling system are constructed of 20-gage galvanized sheet steel mounted on galvanized angle-iron frame. The floor is constructed of 16-gage galvanized sheet steel. Walls, floor, and top sections are insulated with 3 inches of expanded polystyrene.



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Figure 6.--Independently operated condensing units
for the five separate stages of cooling.

TEST INSTRUMENTS AND GAGES

Gages and temperature-measuring instruments were installed in the prototype cooler to provide performance data on the temperature of the evaporator coils; air temperature at selected locations; product temperature during the cooling process; static pressure across the fans; fan and compressor power requirements; and suction and discharge pressure.

It is anticipated that machine performance evaluation will lead to design criteria for more efficient systems in specified commercial applications.

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